3.—Cretaceous dinosaur footprints from Western Australia

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Abstract

Footprints and trackways long known to be exposed in the Lower Cretaceous Broome Sandstone near Broome, Western Australia have been re-examined, and are here attributed to a theropod dinosaur, designated as *Megalosauropus broomensis*, gen. & sp. nov.

Introduction

A preliminary account of the occurrence of large footprints in the Broome Sandstone, of early Cretaceous age, near Gantheaume Point, Broome, West Australia (17° 59′S, 122° 11′E), was published by Glauert in 1952. This account appears to have been based upon reports and measurements, together with a cement cast of one of the prints made by residents of Broome, and not on Glauert's own observations in the field. He attributed the prints to "dinosaurs". Subsequently McWhae *et al* (1958) in their description of the Broome Sandstone, identified the prints more specifically as iguanodont tracks, but gave no reason for this identification.

We visited the exposure on May 25th and 26th 1964 and obtained casts of four of the best preserved footprints, three at Gantheaume Point and one near Riddell Beach. The following report is based on this visit, on a subsequent visit by one of us (D.M.) to the site in August 1964, and on supplementary measurements and checks kindly made for us by Messrs. J. Tapper and M. Gower of Broome.

At this place we wish to express our deep appreciation not only for the assistance mentioned above, but also for much help given us by Mr. Tapper and his brother, M. Edgar Tapper as well as by Mr. Edgar Truslove of the MacRobertson Miller Airlines, in making casts of the footprints, in packing them for shipment, and in the supervision of their transport from Broome to Perth.

Before presenting a description of the tracks and trackways that form the subject of this paper a few remarks will be inserted, to explain our reasons for employing a Linnaean name. In doing this we have been influenced by Peabody (1940 and 1955) and by Baird (1957). As these authors have shown, if designations that clearly indicate the nature of the fossils as tracks and trackways are used, and if the fossils are properly described and interpreted according to the best modern knowledge of such objects, there is every valid reason for giving formal names to them according to the Linnaean system.

"I submit that the characters most diagnostic for the classification of footprints as such, as well as most useful for comparison with skeletal remains, are those which reflect the boney structure of the foot. In most adequately known varieties of dinosaur footprints the presence of articular swellings and pads permits a reasonably accurate analysis of the skeletal pattern." (Baird 1957 p.469).

The tracks and trackways at Broome fulfil the requirements specified by Peabody and by Baird as necessary for the proper study and interpretation of fossils of this nature.

Location

Several groups of footprints were observed. One group in rocks exposed near the north-western end of Riddell Beach consisted of two clearly-defined and one ill-defined print. The second group comprised 10 prints, mostly well-defined, about 150 feet seaward of cliffs near the lighthouse at Gantheaume Point. The third group comprised about 10 ill-defined prints about 200 feet seaward of the same cliffs. The geographical distribution of prints of the second group is shown in Figure 1. Print numbers in Figure 1 represent a field system, later shown to be untenable; they may now be taken as arbitrary numbers.

All three groups are normally covered by sea water and are easily accessible only at very low tides. The more seaward group at Gantheaume Point is exposed only at tides of +1.9 feet or less above the arbitrary datum from which Broome tides are estimated for the North and Northwest Tide Table published by the Harbour and Light Department of Western Australia. The more landward group at Gantheaume Point is accessible below +2.9 feet. The Riddell Beach group is a little higher.

The Broome Sandstone

McWhae *et al* (1958) describe the Broome Sandstone as variegated micaceous sandstones often strongly crossbedded, with subordinate siltstone. A thickness of at least 900 feet has been recorded in bores near Broome. but only about 40 feet are exposed in the type section at Gantheaume Point. The Broome Sandstone is known to lie on the Jarlemai Siltstone, which contains both macro- and micro-fossils of Upper Jurassic age. South of Broome the Broome Sandstone is overlain disconformably by the Parda Formation, from which fossils have not

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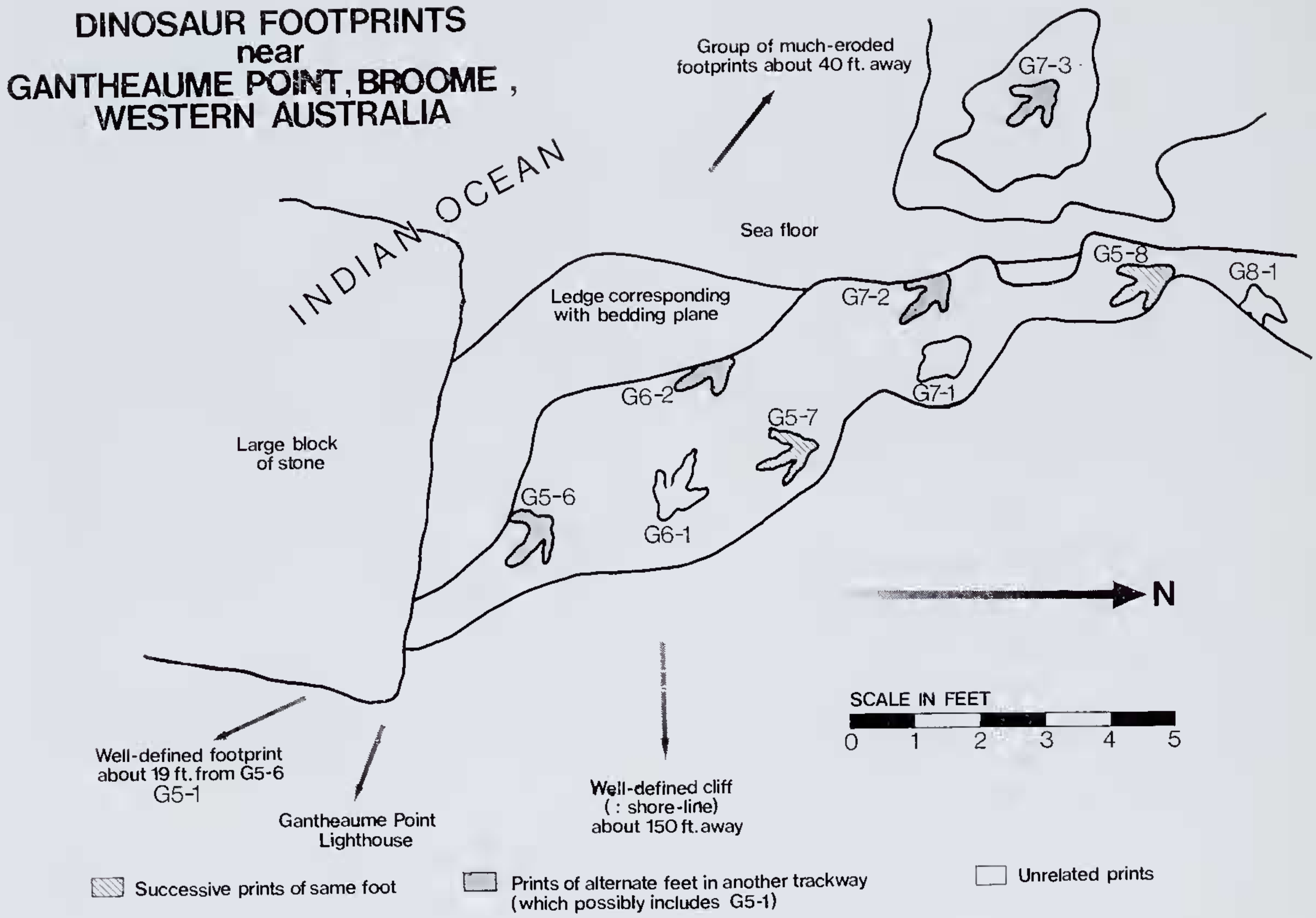

Figure 1

been recorded. McWhae *et al* (1958) tentatively assign both the Parda Formation and (because of "Lower Cretaceous affinities" of the fossil plants contained in it) the Broome Sandstone, to the Lower Cretaceous, possibly the Neocomian.

We found ripple marking, with wave lengths varying from two or three to ten or twelve centimetres, to be characteristic of the Broome Sandstone, which appeared to be quite or nearly horizontally bedded. Presumably each of the three sets of footprints noted above, exposed at different levels, was made at a different time, separated by an interval the duration of which we cannot estimate at present.

Description and Discussion of the Tracks

Megalosauropus, gen. nov.

Diagnosis. Bipedal trackway, with pace angulation about 140°-160°, stride about 2 meters at a normal walk. Individual impressions large (order of 325 millimetres in length), three-toed, and with the angulation of the digits showing an average of about 35° to 45°. Each impression showing second, third and fourth digits with phalangeal formulae of 3 for digit II, 4 for digit III and 5 for digit IV. Trackways probably those of a megalosaurian carnosaur.

Type. Megalosauropus broomensis, sp. nov.

Megalosauropus broomensis, sp. nov.

Holotype. Western Australian Museum No. 66.2.51 (fibreglass mould of print G 5-6).

Paratypes. Western Australian Museum, Nos. 64.6.5 and 64.6.7 (plaster casts of footprints G 5-7 and G 6-1 respectively).

Topotypes. Numerous footprints and trackways in place, at the type locality.

Horizon. Broom Sandstone, of Lower Cretaceous affinities.

Locality. Gantheaume Point, near Broome, Western Australia.

Diagnosis. As given for the genus, above.

Three groups of prints were seen near Broome, and casts were obtained from two of these groups. For the purposes of this present description and discussion, however, only those three casts obtained from the more landward set of trackways at Gantheaume Point, plus studies and photographs of the trackways in situ, are used. The more seaward set of trackways, evidently the ones described by Glauert, were far too battered by wave action to be of any real value for this study. The few prints seen at Riddell Beach, from which one cast was made, did not preserve enough details for effective study. Our study is based on one set of closely associated track ways, all made at one time, since all are exposed at the same topographic and stratigraphic level.

It is evident that the trackways at Gantheaume Point represent one kind of animal, and in all probability a single species. Moreover, these prints appear to be, because of close correspondence in size and structure, conspecific with the prints at Riddell Beach, even though the latter are separated from the former by a horizontal distance of several hundred yards and a vertical stratigraphic separation of several feet.

The cast of one of the prints, (G5-6) shows very clearly the articular swellings and pads which in turn reveal the structure of the foot, so the description is based primarily upon it, supplemented by information from the other two casts. G5-6 is approximately 325 mm. (about 13") in length. The middle of the three toes is the longest, and the somewhat shorter side toes diverge from it at angles of about 35° to 40°. The print indicates a very bird-like foot, with slender toes terminating in sharp claws, and with no webbing between the toes. (It seems reasonable to think that if there had been any strong webs between the toes, such would have been evident in the prints, considering the fine details shown in the impressions of the toes themselves).

The middle digit of G5-6 shows very clearly the articular swellings between four phalanges. These indicate the first phalanx to be longer than the second, the second longer than the third, and the third longer than the fourth. An imprint of the tip of the claw is shown. There is a large "heel print" shown in this track, as in the other footprints from Broome, made by the downward pressure exerted by the third metatarsal at its junction with the proximal phalanx of the third digit. The junctions between the second and the fourth metatarsals and their contiguous phalanges are not recorded in the print, since the distal ends of these shorter metatarsals were elevated to such a degree that they did not come in contact with the ground, even during the implantation phase of the stride, when there was the greatest contact between the foot and the substratum. However, the articular swellings between the first and second phalanges of both the second and fourth digits are clearly indicated. In G5-6 the distal phalanx of the second digit is large, and it is known from numerous fossils of carnosaurian pedes that the claw of the second digit is much the largest of the three claws.

Thus in all respects the details of an individual print of *Megalosauropus* can be correlated point by point with the boney structure of a large carnosaurian pes, particularly of the foot in such genera as *Megalosaurus* itself and *Antrodemus*. It should be added that there is a reasonably close correspondence in size between the footprints here described and the pedes of the two genera mentioned immediately above.

Since certain aspects of foot structure are so well shown in the prints from Gantheaume Point, an attempt is made to indicate the proportions of various phalanges, these being based upon measurements of the casts. In general measurements have been taken at the approximate mid-portions of the articular swellings and pads, these being considered as usually indicative of the joints between phalanges. Peabody (1948 p.402) would place the joints between the ultimate and penultimate phalanges as about coincident with the posterior end of the most distal swelling, a detail with which Baird (1957 pp.456-461) does not agree. Baird would enclose both ends of the fourth phalanx of digit IV within the distal pad. Following Baird's interpretation for the relationships between articular swellings and pads and the boney structure of the foot, and making direct comparisons of these footprints with the bony structure of the foot in *Antrodemus* (because it is available, and closely related to tthe form under consideration) results have been obtained as shown in the accompanying Table 1.

TABLE 1

Comparisons of foot dimensions in Megalosauropus *and* Antrodemus.

	Megalosauropus (Broome G5-6) Length of phalanges derived from measurements between digital swellings and pads of footprints Lengths (mm.)	*Antrodemus* A.M.N.H. 5753 Measurements along ventral surfaces of phalanges Lengths (mm.)
Digit II		
Phalanx 1	—	118
2	50	83
3	55 (110% of phalanx 2)	101 (122% of phalanx 2)
Digit III		
Phalanx 1	100	134
2	60 (60% of phalanx 1)	89 (66% of phalanx 1)
3	56 (56% of phalanx 1)	71 (53% of phalanx 1)
4	46 (46% of phalanx 1)	66 (49% of phalanx 1)
Digit IV		
Phalanx 1	—	90
2	55	65
3	40 (73% of phalanx 2)	43 (66% of phalanx 2)
4	28 (51% of phalanx 2)	36 (55% of phalanx 2)
5	23 (42% of phalanx 2)	62 (95% of phalanx 2)
	Length of footprints including Metatarsal III pad —325	Length of Digit III phalanges + Metatarsal III articulation —435

TABLE 2

Comparison of trackway characteristics in Megalosauropus *(Broome, W.A.) with those of an unnamed carnosaur from Glen Rose, Texas, U.S.A.*

	Megalosauropus	Glen Rose, Texas
Stride (mm.)	2048 1843 av. 1946 (approx. 6'4")	3150 3090 3120 av. 3120 (approx. 10'3")
Pace (mm.)	1126 av. 1065 (approx. 3'8")	1610 1540 1550 1570 av. 1567 (approx. 5'2")
Pace Angulation	160° 140°	149° 152° 163°
Interpes distance		Essentially 0 (The tips on the inner toes are normally on the mid-line)
Angulation of digits	35° — 45°	37°

Four prints at Gantheaume Point in the more landward exposure form a trackway, these being the prints G7-3, G7-2, G6-2 and G5-6 (see Figure 1). In addition, G5-8 and G5-7 appear to be successive prints of the same foot in another trackway. The first of these two trackways is oriented about N 140°, the second about N 155°.

The figure published by Glauert, (1952) showing the more seaward group of tracks at Gantheaume Point, indicates two trackways, more or less parallel to each other and both oriented in the same direction, toward the south. It is interesting that the two trackways in the landward set, mentioned above, are also directed in a generally southerly direction. The four prints, G7-3, G7-2, G6-2 and G5-6 show a pace of more than 1 metre (about 3' 6" to 3' 8") and a stride (6' 8") of about 2 metres. This may be compared (see Table 2) with a trackway made up of five prints from the Lower Cretaceous Glen Rose Formation of Texas, now on display in the Brontosaur Hall of The American Museum of Natural History. In the Glen Rose trackway the strides ranges between 3.09 metres (about 10' 2") and 3.15 metres (about 10' 4"). The Texas prints are larger than those at Gantheaume Point, so the difference between the stride in the two dinosaurs is not surprising. The ratio of track length to stride is remarkably similar in the two sets of trackways, as shown below (all dimensions in millimetres):—

	Gantheaume Point, W.A.	Glen Rose, Texas
Length of print	325 (G5-6)	a. 500 (smallest) b. 520 (largest)
Length of stride	2048	c. 3090 (shortest) d. 3150 (longest)
Ratio		
Length of print/ Length of stride	16%	(a/d) 16% (b/c) 17%

The Gantheaume Point trackways show that the feet were oriented in fore and aft fashion; that is, the axis of the middle toe is more or less in line with the direction of the stride. The same is true for the Glen Rose trackway. There was generally no twisting of the foot while walking in these large carnosaurian dinosaurs; rather they walked in a very bird-like fashion, as is certainly to be expected from their great weight. Any marked twisting of the foot during locomotion would have been not only inefficient but also dangerous for animals of this size. In this respect one may compare them with heavy mammals of the present time, such as horses or rhinoceroses or elephants, in which the foot is constructed for rectilinear action during locomotion.

Moreover, the *Megalosauropus* trackways show, as does the Glen Rose trackway, that these giant carnosaurs swung the leg anteroposteriorly, bringing the foot down close to the mid-line, again as might be expected in animals of such great weight. This would have maintained the feet directly beneath the body and in line with the centre of gravity. Thus the inner toes of the right and left feet commonly meet the midline in these trackways and the pace angulation is wide, being 140°-160° in the Gantheaume Point trackway and 149°-163° in the Glen Rose trackway.

Particular attention has been given in the foregoing discussion to a comparison of the prints and trackways of *Megalosauropus,* found in the Broome Sandstone. with the prints and trackway of the as yet unnamed carnosaurian dinosaur from the Lower Cretaceous Glen Rose formation of Texas. It has been shown that close resemblances exist between the impressions made by large predatory dinosaurs that were living on opposite sides of the world during early Cretaceous time. Moreover, these resemblances are one indication of the wide distribution of the large theropod dinosaurs, during early Cretaceous history, and by inference of the various gigantic herbivorous dinosaurs upon which they fed.

In addition to the trackways described above, there are some other prints and trackways that give additional information as to the distribution of the carnosaurs during the early phases of Cretaceous history. Of particular importance are the trackways described by Sternberg (1932) from the Lower Cretaceous sediments along the Peace River, British Columbia. Several hundred footprints, many of them associated in trackways, were found at this locality, representing, according to Sternberg's description, some six genera. Although Sternberg did not attempt to assign the prints he described to categories larger than the genus, it is quite evident that one type, namely *Irenesauripus*, represents a large carnosaur. *Irenesauripus mclearni*, in which the length of the individual footprint is 380 mm. and the average stride is 940 mm. is rather close to *Megalosauropus* in size. while *Irenesauripus occidentalis*, with a footprint length of 500 mm. and "stride" (really pace) stated to be about 1000 mm. may be compared with the tracks from Glen Rose, Texas (Sternberg 1932 p.62 cf. p. 65).

Mention should be made also of the many imprints found in Lower Cretaceous near-shore deposits in Georgia, U.S.S.R., and described by Gabouniia (1951). One genus (*Satapliasaurus*) would seem to represent a theropod somewhat smaller than *Megalosauropus*, since its prints (assigned by Gabouniia to three different species) show a range of print length from 220 to 250 mm. and of a stride from 600 to 700 mm.

It seems obvious that megalosaurian carnosaurs were even more widely distributed than these several records indicate. The bones and prints of Lower Cretaceous iguanodonts have been found at many localities in Europe, in central Asia, in North America, in South Africa, in the island of Spitzbergen, and in Australia. By an inference opposite to the one made three paragraphs above, it may be supposed that where these large herbivores wandered there would also be predators, in other words megalosaurs, to feed upon them.' All of this points up the fact that there were continental connections permitting the large dinosaurs to migrate widely throughout the world during Middle and Late Mesozoic times. The presence of *Megalosauropus* in Western Australia makes one more link in the chain of evidence as to the distribution of these interesting reptiles at the time of their dominance.

Conclusions

From the foregoing description it can be seen that *Megalosauropus*, as known from trackways exposed at Gantheaume Point. near Broome, Western Austrlia, is a large carnosaurian dinosaur with most of the attributes in the individual footprints and in the trackways that are to be expected in such an animal. Since the Broome Sandstone is now regarded as of early Cretaceous age, being placed well down in the Neocomian (see McWhae *et al*, 1958) these trackways may be regarded as representative of a large megalosaur, perhaps even of *Megalosaurus* itself. But since these are only the trackways they have been given a separate designation, for the reasons discussed by Peabody (1940 and 1955) and Baird (1957). They indicate a dinosaur similar to the one (as yet unnamed) that made the Glen Rose trackway, this latter being somewhat later (of Aptian age) than the one in the Broome Sandstone. Finally, the trackways of *Megalosauropus broomensis* give valuable new evidence as to the world-wide spread of the carnosaurian dinosaurs in early Cretaceous time.

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